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POLLUTIONAL PROBLEMS AND RESEARCH NEEDS FOR AN OIL SHALE INDUSTRY

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SECTION I

CONCLUSIONS

1. The stabilization of spent shale residues is the major environmental problem confronting the developing oil shale industry and EPA. Reclamation of the disposal site is second in priority to effective stabilization.

2. Freeze-thaw conditions and water saturation can result in the mass movement of spent shale through slumping and sliding. Adequate measures can be taken to prevent this occurrence.

3. Because of the water requirements for spent shale disposal, process waters need not be a pollutional problem. Furthermore, a closed system for water seepage at the disposal site will prevent pollution by salt transport.

4. Solutions to other environmental problems associated with commercial oil shale processing are actively being sought or will be realized before the industry develops to full-scale. Therefore, these are areas of lesser concern in comparison to spent shale stabilization.

5. Research needs remaining in the field of oil shale development that require a continued EPA effort include: delineating groundwater resources for the tri-state oil shale region; establishing pollution control guidelines and effluent limitations for the industry; monitoring oil shale development; obtaining environmental base line data; and preparing an assessment of total environmental impact.

SECTION II

RECOMMENDATIONS

1. In disposing of spent shale, the industry needs to concentrate efforts on mass stabilization.

2. There are gaps in available groundwater information for the area of proposed oil shale development. In addition, the impact of the industry on this water resource is uncertain. For these reasons, EPA should conduct or support a study of groundwater qualities, pumping yields, locations, and movements, especially emphasizing the proposed lease sites.

3. As the unit operations of the industry are revealed, EPA should conduct surveys of water quality for the streams affected, and determine waste loadings and treatment efficiencies. Establishment of effluent limitations and pollution control guidelines should be based upon this information.

4. Procedures should be implemented to control high-grading of the shale, to avoid oil extraction at the expense of aluminum and bicarbonate compounds, and to insure optimized techniques in backfilling with spent shale residues.

5. Continued EPA involvement in environmental aspects of oil shale research and in monitoring the developing industry is recommended.

SECTION III

INTRODUCTION

The United States faces an unprecedented energy crisis and a long-term need for developing major new domestic sources of energy. One such untapped source is oil shale. Oil derived from shale is currently receiving attention for several reasons. The average price of domestic petroleum is about $7.00 per barrel. The estimated price range of shale oil is $4.00 to $6.00 per barrel, dependent on many variables including the degree of upgrading or prerefining. Prerefining of the retort product (shale oil) yields a premium feedstock of constant quality, containing virtually no sulfur. Strategically, oil shale is a domestic resource capable of providing oil from a single, small geographic area for an unusually long duration (perhaps 200 years). Although major deposits are scattered from Texas to the Great Lakes, the areas having at least 25 feet of continuous beds yielding >25 gallons of oil per ton are confined to the Green River Formation underlying 16,500 square miles in Colorado, Utah, and Wyoming (Figure 1). These beds are estimated to contain 660 billion barrels of oil, a figure comparable to the world's proven reserves of crude petroleum. Roughly 75 percent is contained in the 1,600 square mile Piceance Creek Basin, marking this area as the probable site of the first commercial oil shale operation.[1] Of the proven reserves, roughly 80 billion barrels are considered to be recoverable using current technology. For comparative purposes, approximately 100 billion barrels of petroleum have been produced by the United States since the Civil War.

Surface water in the area of the Green River Formation drains to the Colorado River. Pertinent quality and flow data compiled by USGS are

presented in Table 1. Sampling locations correspond to the numbered designations in Figure 1.

At present, the most economical method for extracting the organic material from shale involves the destructive pyrolysis of crushed ore at atmospheric pressure at approximately 900° F. Following this retorting process, the organics are released as an oil vapor. The hydrocarbon condensation products of the vapor constitute shale oil; its characteristics depend on the shale source and the retorting procedure utilized. Compared to petroleum, the product is a heavy, viscous oil having a high pour-point and elevated nitrogen and sulfur content (Table 2).

Two methods of processing oil shale are receiving consideration at this time. The first has been tested extensively on a pilot scale and will probably constitute the initial stage of the industry. It consists of mining oil shale, crushing and retorting the material in surface operations, and disposing of spent shale residue. Following utilization of wastewater in quenching, the net products are shale oil, mine overburden, and spent shale ash. The second method of extracting oil involves retorting oil shale in place (in situ). The technical aspects of this method are in the experimental stages of development. The subsurface shale formation is first penetrated by drilling. In one approach, conventional or nuclear explosives are placed beneath or within the formation and detonated. It is believed that a subsurface rubble pile surrounded by fractured shale will be the result of a contained nuclear explosion. Another approach consists of combining conventional explosives with hydraulic fracturing to increase permeability of the formation. In either event, a network of wells is then installed. The fractured shale is retorted with an induced fire front, and a water-shale oil mixture is pumped to the surface for separation. The net products of an in situ operation are shale oil and a wastewater that requires treatment. Above-ground retorting will likely be utilized initially for full-scale operations since the process is more advanced than the in situ method at the pilot scale.

Industry and the Federal Government are directing efforts toward developing oil shale resources on private and public domain in the Green River

Table 1. SURFACE WATER DATA IN THE VICINITY OF THE GREEN RIVER FORMATION

Stream Sample Point	Sampling Point Description	Weighted average 10/61 - 09/62[2]							Wt. avg. 1951-1960[3]
		pH	TDS (mg/l)	Ca (mg/l)	Na (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Mean Flow (cfs)	Mean Flow (cfs)
1.	Colo. R. near Glenwood Springs, Colo.	7.5	240	--	27	114	60	3,305	--
2.	Colo. R. near Cameo, Colo.	7.6	328	52	49	139	74	5,525	--
3.	Colo. R. near Cisco, Utah	7.7	488	74	64	150	182	9,250	6,475
4.	White R. near Watson, Utah	7.9	447	--	62	206	149	920	680
5.	Yampa R. near Maybell, Colo.	7.3	180	--	18	108	47	2,060	1,450
6.	Green R. near Green River, Wyo.	7.8	267	--	26	168	80	2,005	1,615
7.	Green R. at Green River, Utah	7.9	395	--	49	178	143	8,050	5,550

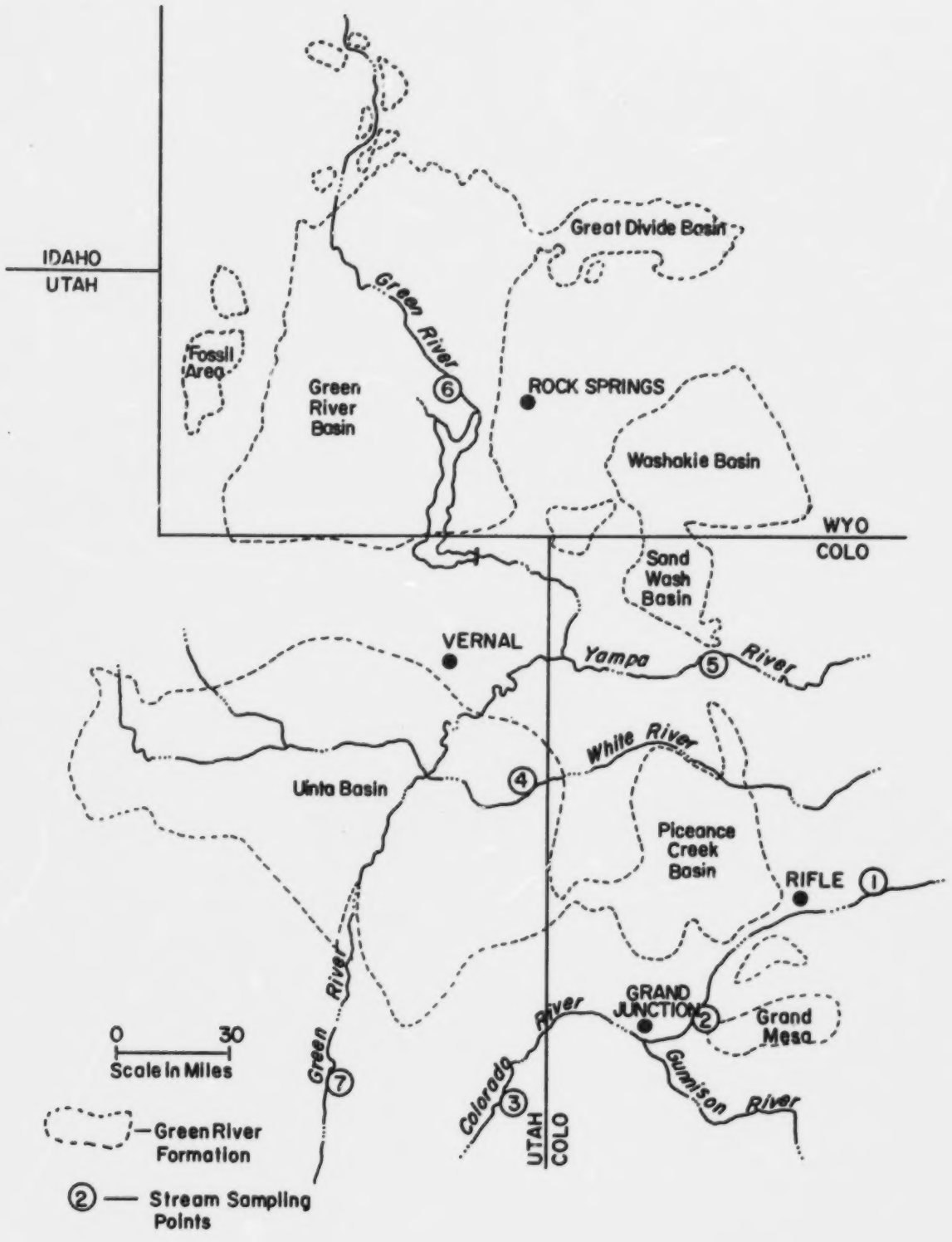

FIGURE 1 - BOUNDARIES AND SURFACE DRAINAGE OF THE GREEN RIVER FORMATION

Table 2. COMPARATIVE CHARACTERISTICS OF PETROLEUM AND SHALE OIL[4, 5]

Source	Gravity °API	Sulfur Wt %	Nitrogen Wt %	Pour Point ° F	Analysis of Distillates Boiling Below 600° F (Vol. %)		
					Saturates	Olefins	Aromatics
Midcontinent Petroleum	39.0	0.14	0	5	90	0	10
Shale oil from Colorado shale by five retort methods	16.0-25.7	0.6-0.8	1.6-2.2	60-90	26-36	36-46	28-32

Formation. The Colony Development Operation has begun construction of a 50,000 bbl/day plant. Government interest results from the occurrence of approximately 75 percent of the high-grade oil shale deposits on public land, the majority under the jurisdiction of the U.S. Department of Interior. The Interior is completing a program for leasing oil shale property to industry for testing of the economics of production and safeguarding the environment.

Future exploitation of public oil shale reserves will be based on initial program results. Six leases (5,120 acres each) have been offered for sale on a competitive basis in 1974. The sites were selected to test the possible mining methods, surface, underground, and in situ. The extraction procedure will depend upon the depth of overburden and the thickness and structural integrity of the oil shale beds. For example, in the center of the Piceance Creek Basin of Colorado, high grade shale occurs in beds up to 2,000 feet thick, but overburden may be as great as 1,000 feet. Current open-pit technology in coal mining is limited to approximately 400 feet of overburden. The room-and-pillar method, or another underground procedure, would be indicated in this instance. The method employed will depend upon the bed thickness and the degree of fracturing.

Pursuant to Section 102(2)(C) of the National Environmental Policy Act of 1969 (see Appendix A), the Department of Interior initiated a study of the leasing program in 1970 with special emphasis on environmental considerations. At the Department's request, the States of Colorado, Utah, and Wyoming each formed committees represented by Federal, State, and local government and industry. The committees prepared formal reports describing reserves, lease sites, shale processing systems, and environmental factors within each State.[6, 7, 8] The Department of Interior has drafted a statement on environmental impact that draws upon information gathered from the State reports, other Federal agencies, interested State and local agencies, citizens at large, and standing Federal regulations.[9]

The present report defines the areas of environmental concern and research needs based on the Federal and State reports, in-house and extramural research, a review of the literature, and personal contacts.

SECTION IV

AREA OF MAJOR ENVIRONMENTAL CONCERN

Aboveground retorting operations will result in the surface disposal of significant quantities of retorted oil shale residues for two reasons. First, when raw shale is crushed prior to retorting, the volume per unit mass is doubled. Approximately 40% of the volume is lost in retorting.[10] It follows that spent shale occupies a volume roughly 20% greater than raw shale in place. Second, spent shale disposal at mine sites cannot occur until adequate void space is available. The magnitude of solid waste disposal is difficult to predict at this time, for it will depend upon the grade and crushing requirements of raw shale, the retorting method and temperature to which the shale is subjected, the amount returned in mining operations, by-product usage in the immediate area (highway base material or construction aggregate), and whether or not saline minerals are recovered. Surface mine spoils and crushing fines unsuitable for retorting magnify the solid waste disposal problem. However, using the 20% figure above, a 50,000 bbl/day plant could produce as much as 260,000 ft^3/day spent shale in excess of that returned to the mine (note: assuming raw shale assays 25 gal./ton and occupies 15.5 ft^3/ton in place). This production would be sufficient to cover Washington, D.C. (area 65 square miles) to a depth of 1/2 inch per year. The proposed one million bbl/day minimum for economic operation in Colorado would increase the figure to almost one foot per year.

The probability that long reaches of canyons will be filled with waste shale to depths of perhaps 600 feet indicated a need for testing the stability of the material to rainfall and snowfall on a pilot scale. This

would allow a meaningful prediction of the ultimate environmental impact. Accordingly, Colorado State University was awarded an EPA grant to perform a rainfall study using retorted shale residues from the three most promising aboveground retorting methods most thoroughly tested at the time.[11, 12] These were the Bureau of Mines gas-combustion process, the Union Oil Company counter current process, and The Oil Shale Corporation (TOSCO) process (Appendix B--process descriptions; Appendix C--spent shale characteristics). The three processes were examined to determine variations in the spent shale residues resulting from crushing and retorting operations. Maximum raw shale size for the Bureau of Mines and Union processes is 3.5 inches, while that for the TOSCO method is 0.5 inch. Virtually all of the carbon residue is burned off retorted shale in the Union and Bureau of Mines retorts. The residual solid wastes are large, fused clinkers from the Union process, particles up to 3 inches from the Bureau of Mines retort, and a finely-divided, black residue from the TOSCO process. Of the three processes, the TOSCO processed shale was afforded the most consideration as this process was the closest to commercial development.

A description of TOSCO shale and its emplacement and compaction on the facility is given in Appendix D. Thirteen applications of rainfall were made, amounting to three years of precipitation in the area proposed for oil shale development. Rainfall events were spread over a three month period to allow for surface drying between applications. At the conclusion of the rainfall investigation, snowfall (artificial and natural) studies were conducted for the U.S. Bureau of Mines.[13] A total of 4.75 inches of water as snow was applied to the facility during four snowfall events.

Water penetration was negligible in the rainfall studies. The change in moisture content one foot below the surface at the downstream end was only about 10% from beginning to end of the study. The wet shale surface several hours after rainfall remained sufficiently firm to support walking and register little or no footprints. The surface

runoff contained 200-700 mg/l total dissolved solids. Black settleable fines were transported in the runoff at rates up to 0.1 pound per square foot of surface area per hour of application.

Results of the snowfall study revealed that the concentration range of dissolved solids in the runoff (50-450 mg/l) was lower than in the rainfall-runoff. Because of the low rate of runoff from melting snow, suspended fines were negligible. The important findings related to percolation. Long periods of contact as the snow melted permitted water penetration into the bed of residue and subsequent saturation to the maximum depth of the experimental plot (2 feet). Saturation reduced the effects of compaction, and the surface no longer supported walking.

It is important to note that the results are for one sample produced by only one retort method under a single set of retorting conditions. The exact nature of retorted shale at the time of deposition in the environment and its fate and effects in that environment are unpredictable. However, the experiments reveal that in order to stabilize a disposal site containing shale of the general nature tested, moisture content of the contained shale must be controlled.

Conditions approaching water saturation could ultimately result in mass movement brought about by reoccurring slope failures (slumping, sliding, or seismically-induced liquifaction). The following methods are suggested to prevent this situation:

(a) Preliminary assessment of a suitable disposal site must be made on the basis of the relative danger from erosion. Criteria include evidence of past erosion, water flows, tendency for flash flooding, elevation changes, and remoteness.

(b) The base footing of the pile could become a critical factor if the seasonal variation in groundwater tables results in free water on or near the surface. Spring discharge from alluvial aquifers may represent the total flow of normally-dry stream beds. Compression of the soil material in the canyon floor could result in the rise of free water to the base of

the pile and saturation of the lower layers of the pile. To prevent this occurrence, the effective water table should be lowered by means of drainage channels in the canyon floor.

(c) If spent shale is deposited as a water slurry, retaining dikes should be designed to facilitate shale dewatering and prevent a state of prolonged saturation. An approach similar to the design of dams for mill tailings is suggested.[14] Due to high salinity and the water requirements for hydraulic transport, it is expected that runoff and leach-water seepage will be intercepted by catch basins at the toe of the embankment and diverted through sealed trenches and ponds for recycle.

(d) Upstream surface water and side wall canyon runoff should be diverted around the dump site to prevent shale saturation. As an added benefit, this will lower the water table in shallow aquifers beneath the pile.

(e) Erosion during heavy rainfall could be minimized by contouring the surfaces in benches.

(f) The contained shale should be equipped with instrumentation to monitor the moisture content and the free water tables and water movement. Following final compaction of the shale surface, exposed surfaces should be permanently sealed to water penetration. Sealing could be accomplished economically and effectively by working into the surface a material such as bentonite clay.[15] The resulting impermeable barrier should be covered with a layer of sand or crushed rock followed by native overburden or conditioned soil. The total depth of fill over the barrier should exceed the freezing line depth of the region by a margin of safety. Soil surfaces may then be revegetated, taking advantage of past successes by the industry and using native plant cover with reasonably shallow root structures.[16]

Much emphasis has been placed on revegetating spent shale dumps to achieve stability, support native grazing animals, or restore the aesthetic beauty of the countryside.[6, 7, 8, 9] These references suggest that the shale pile can be compacted, covered with an enriched soil, and

revegetated; thereby the site is stabilized and the aesthetics preserved. However, drought, fires in dry seasons, or overgrazing could result in the loss of the vegetative cover followed by soil erosion, exposure of the shale surfaces, water penetration, and saturation. The approach previously presented is believed to offer a greater safeguard to the environment: (1) prevention of shale saturation with effective barriers, (2) drainage of water away from the top surface barrier by means of a sand or rock layer, (3) retention of the sand layer with overburden, and (4) stabilization of the overburden with a vegetative cover unmolested by foraging animals. This may be accomplished by fencing off areas planted in staple browse, such as sagebrush and juniper, or by covering with "unattractive" plants which have grown by natural succession on abandoned mine sites in the area.

SECTION V

OTHER AREAS OF ENVIRONMENTAL CONCERN

RETORT WATER

Retort water is the waste effluent separated from shale oil following oil shale pyrolysis either in the formation underground (in situ) or aboveground. The volume and characteristics of the waste are dependent upon the process and the operational parameters of retorting. With process control, little or no water may be produced. The upper limit anticipated is 1.4 weight percent of raw shale, or 3 gal./ton.[10] The wastewater poses a serious problem if released to surface or subsurface fresh water. It contains significant concentrations of dissolved organics and inorganics, emulsified oil, and finely divided suspended matter. Table 3 is an example but should not be construed as representative of the waste on a commercial scale.

Wastewater generated from aboveground retorting operations will likely be consumed as makeup water for dust control (at shale conveyors and crushers) and for spent shale disposal (quenching, hydraulic transport, and compaction). The Colony Development Operation has proposed recovery of ammonia and sulfur from foul wastewaters generated by the TOSCO retorting process. Salt leaching of spent shale will result from the usage of retort water in disposal operations (Appendix C contains leachate characteristics). However, proper waste pile construction (Section IV) would prevent salt from leaching into a fresh water resource. Volumes of water in excess of retort water will be required for quenching, moistening, and dust control.

Table 3. ANALYSIS OF RETORT WASTEWATER FROM THE BUREAU OF MINES PROCESS*

Total Solids (103° C), mg/l	3,000
Nonvolatile Total Solids (600° C)	1,700
pH	8.5-9.5
Ammonia (Direct Nesslerization), mg/l NH_3	2,500
Chemical Oxygen Demand, mg/l Ox. Dem.	6,700
Total Carbon, mg/l C	2,150
Nonvolatile Organic Carbon, mg/l C	1,600

Predominant Inorganic Species: Na^{+1}, Ca^{+2}, NH_4^{+1}, Cl^{-1}, SO_4^{-2}, HCO_3^{-1}, CO_3^{-2}.

Predominant Organic Species: Complex mixture of dissolved and suspended organics.

*Analysis by the Bureau of Mines, Laramie, Wyoming.

Wastewater generated from in situ retorting will require special handling. The U.S. Bureau of Mines, Laramie, Wyoming, in conjunction with its in situ experiments, is studying constituents of the wastewater, treatability, and possibilities for by-product recovery.[17] Based on the results of bench studies, the group has proposed a treatment scheme as follows: (1) lime and heat addition to remove carbonates, ammonia, and some organics; (2) carbon adsorption to remove the balance of organics; and (3) ion exchange to remove the remaining ionic species.[18]

Regeneration of the ion exchange media will yield a solution of ions more concentrated than that of the carbon adsorption effluent. The end results of treatment are purified retort wastewater and a relatively smaller volume of brine from the regeneration process that will require additional treatment or control.

PROCESS WATER FROM SHALE-OIL UPGRADING

It is anticipated that shale-oil refining to finished products will not take place in the region of oil shale development because of the limited availability of water for refinery cooling operations. However, several unique characteristics of crude shale oil suggest the advisability of pre-refining steps before pipelining to major petroleum refining centers, water availability permitting. Compared to good petroleum crude, shale oil has a high pour-point and viscosity (making pipelining difficult at cold temperatures), is unstable (due to a high olefinic content), and possesses greater concentrations of sulfur and nitrogen (nitrogen reduces the life of refinery catalysts). The retorting process influences these characteristics; that is, oils produced by The Oil Shale Corporation (TOSCO), the Bureau of Mines, and the Union Oil Company processes would be expected to have different viscosities.

Recycle coking with hydrostabilization is an effective means of shale-oil upgrading (Figure 2). Except for nitrogen concentration, the liquid product is acceptable to petroleum refineries and is amenable to pipelining. Catalytic hydrodenitrogenation incorporated into the upgrading process or performed at the refinery destination will produce a premium feed stock with satisfactory nitrogen levels.[19]

The products of coking and hydrostabilization are hydrotreated synthetic crude, coke, fuel gas, and a small amount of hydrogen sulfide. Wastewaters are expected from cooling tower blowdown and various unit processes, containing dissolved materials (organic and inorganic) and entrained solids. These will be consumed in spent shale quenching and wetting. With proper construction of shale disposal sites, salt transport by leaching and seepage will not occur.

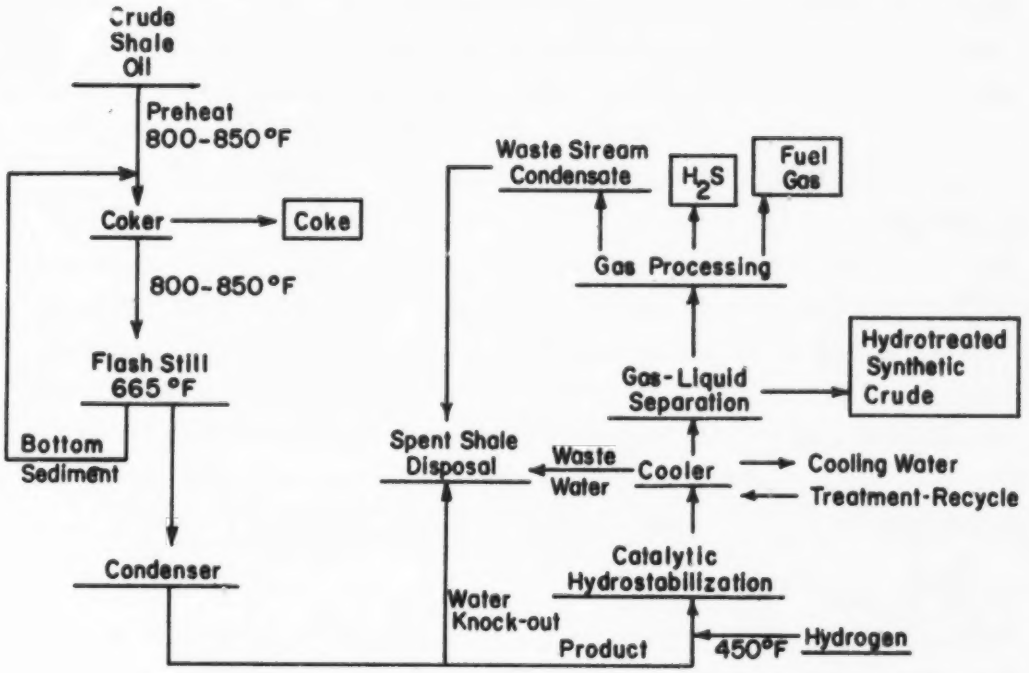

FIGURE 2 - SHALE OIL UPGRADING PROCESS[19]

DEWATERING OPERATIONS

Mining may permit migration of groundwater into the area of operation and necessitate dewatering. Mine water of poor quality will serve in meeting the large water requirement for dust control and spent shale disposal. Requirements for cooling water will more than offset mine water having low salinity.

In situ retorting will include preliminary formation fracturing. The economics of large-scale production favor a contained nuclear detonation for this purpose. Nuclear fracturing and in situ retorting will be confined to the deeper, thicker oil shale deposits. Often the deposits underlie a permeable, highly saline aquifer. Water wells to these depths have yielded as much as 500 gpm. Total dissolved solids concentrations approaching 17,000 mg/l have been reported.[6] The volumes and salinity will vary with depth and location in the tri-state area. If fracturing results in the migration of water from an aquifer into the retorting zone, its quality may preclude disposal to even the poorest quality surface streams in the area (see Table 1). Assuming the water contains no radioactivity (see Section II, 5), it might be charged to a compatible subsurface saline aquifer, subject to State permit and Federal policy.[20]

MINERAL RECOVERY

Saline minerals in significant quantities are bedded in deposits of oil shale which may be 1,800 feet below the surface and up to 900 feet thick.[21] The depth of the minerals relative to the surface suggests that should the minerals be exploited, recovery will coincide with room-and-pillar mining or in situ retorting operations. Dawsonite (a sodium aluminum dihydroxycarbonate) and nahcolite (a sodium bicarbonate) appear to be the most economically attractive at this time. It is not known whether industry will attempt to recover these minerals, although research in the area is active in both industry and government circles. The Department of Interior's policy concerning the production of shale oil at the expense of another mineral resource is also unclear at this time.

Aboveground retorting with concomitant saline mineral recovery will result in a spent shale residue with characteristics different from those not recovering saline minerals. For example, the recovery of alumina from dawsonite and soda ash from nahcolite may produce (depending on the retorting process) a spent shale residue which has:

1. a smaller mean particle size, due to a fine crushing requirement;
2. an inorganic composition which has been chemically altered because of higher process temperatures;
3. a particle surface devoid of elemental carbon;
4. a reduced leaching capability, since mineral recovery may include acidic or alkaline leaching.

No information is available regarding the effects of weathering on the residue. The limited volumes of the residue produced relative to retorted shale and the uncertainty of recovery by industry make this an area of lesser environmental concern.

It is anticipated that the process water from the leaching process will be recycled in the saline mineral recovery operation. Waste leach water from aboveground recovery will be consumed in makeup water for spent shale disposal. Mineral recovery coincidental with in situ retorting may result in waste leach water containing radionuclides that require special treatment or disposal. The Bureau of Mines, Laramie, Wyoming, is investigating the extraction of alumina from dawsonite-containing shale in conjunction with in situ retorting. The studies may provide information as to the characteristics and disposal of waste leach water, neither of which is available at the present time.

RADIOACTIVE CONTAMINATION OF GROUNDWATER

In situ methods should be the last employed by industry at full-scale. Operational problems including low oil recovery and the inability to control the direction of fire front have been experienced by the Bureau of Mines in a field test a Rock Springs, Wyoming.[22] The Department of

Interior's policy regarding partial recovery of an oil resource is unclear at this time and will further influence in situ testing.

Contained nuclear devices have been proposed for formation fracturing prior to inducing a fire front and retorting oil shale in place. One purpose for their usage is to create extensive fracturing while holding the cost per volume fractured to a minimum. Fracturing invites infiltration of groundwater into the oil shale formation, otherwise impervious to water. The possibility of venting radioactive gases into overlying groundwater formations could result in contaminated groundwater. The problem may be prevented by means of (1) precise pre-shot geologic and hydrologic reconnaissance, and (2) the application of previous results with contained nuclear detonations in similar rock types.

AIRBORNE EMISSIONS

Without precautionary measures, most of the industrial operations, including drilling, blasting, crushing, conveying, retorting, and upgrading, will result in air pollution through emissions of sulfur compounds, nitrogen compounds, hydrocarbons, and dust. Mine regulations regarding circulating air during blasting will impact dust emissions. The geographic area is prone to temperature inversions that could concentrate air pollutants in excess of State air quality standards. Methods of controlling these emissions are currently in use for the mining and oil refining industries: recovery of elemental sulfur; precipitators and enclosed systems for containing dust; and smokeless flares for venting volatile hydrocarbons. The application of these control methods to the oil shale industry is difficult to predict, since the wastes requiring treatment will differ according to the processes selected for commercial production. Elimination of airborne emissions can be accomplished by closely monitoring the industry, implementing applicable techniques, and enforcing air pollution legislation.

SECTION VI

RESEARCH NEEDS

1. Surface water information regarding flows, quality, and commitments indicates that the water requirements for an oil shale industry may exceed the availability of uncommitted water and/or result in water quality degradation sufficient to violate downstream agreements. In view of this, there is a heightened interest in groundwater resources within the regional confines of prospective oil shale development. Although data on groundwater quality, pumping yields, location, and movement are available for the Piceance Creek Basin of Colorado, similar information for the tri-state area is incomplete.[23] A study should be conducted emphasizing the active industrial sites and USDI leases. The findings would permit industry and government to evaluate the following groundwater considerations for each site:

(a) availability of groundwater for process water,

(b) venting of radioactivity to overlying groundwater as a result of nuclear fracturing,

(c) communication between fresh and saline groundwater aquifers caused by nuclear fracturing,

(d) dewatering requirements for mining operations and in situ retorting,

(e) continued groundwater seepage and grouting requirements at abandoned sites of mining, subsurface spent shale emplacement, and in situ retorting,

(f) compatible salaquifers for injection purposes in the event produced brines cannot be consumed as process water or treated, and

(g) annual variation in shallow groundwater table at the surface site of spent shale disposal.

2. Prior to the establishment of mining and retorting facilities, base line data are needed to assess the environmental impact of an oil shale industry. Areas of interest to be studied include the following environmental systems: surface water (including aquatic organisms), groundwater, air, and terrestial species. The study should consist of the following:

(a) preparation of monitoring guidelines,

(b) supplementation of existing monitoring stations to complete the network,

(c) network testing under operating conditions,

(d) gathering of base line data, and

(e) preparation of a base line report.

Ultimately, base line conditions for each of the systems should be established for the reaches of the upper Colorado River Basin which are impacted by the oil shale resource. Initially, attention should be directed to those specific sites where early activities by industry are indicated at this time; for example, the Colony Development Operation site along Parachute Creek, and the USDI lease sites.

3. A continuing assessment of total environmental impact is needed throughout the course of oil shale development. A part of the assessment will be based on data obtained by operating the monitoring network and measuring deviation from base line conditions. The final impact evaluation will serve as a basis for EPA recommendations on future resource development (for example, oil shale versus western coal) and to revise research, development, and demonstration plans.

4. EPA should conduct research necessary to prepare pollution control guidelines for sites of oil shale mining and spent shale disposal. Mining investigations should include groundwater protection from in situ fracturing, retorting, and abandonment. Studies of spent shales wetted with waste process waters will be required. In addition, control and treatability studies will be needed to prepare effluent limitations for in situ-generated retort water, considered to be a point-source discharge.

5. The stability to mass movement of surface spent shale dumps poses the most serious threat to the environment. It is imperative that industry take every precaution to assure that no portion of the dump approaches water saturation. To assure stability, continuous monitoring will be required. As operational parameters change in working a lease site, the resultant spent shales, each having a new set of characteristics, should be thoroughly tested before disposal. Spent shale disposal sites will require periodic examination during construction and following abandonment. Specific parameters to be considered include: moisture versus depth and position in the pile and in the dikes, stability to slide (resistance to shear), and compression strength--all as a function of ambient temperature and precipitation.

SECTION VII

REFERENCES

1. Williams, F. E., et al. Potential Applications for Nuclear Explosives in a Shale-Oil Industry. U.S. Bur. Mines, Report No. IC8425, 1969. 37 p.

2. Quality of Surface Waters of the United States, 1962. Part 9. Colorado River Basin. U.S. Geological Survey Water Supply Paper 1945. 1964.

3. Compilation of Records of Surface Waters of the United States, October 1950-September 1960. Part 9. Colorado River Basin. U.S. Geological Survey Water Supply Paper 1733. 1964.

4. Matzick, A., et al. Development of the Bureau of Mines Gas-Combustion Oil-Shale Retorting Process. U.S. Bur. Mines, Bulletin 635, 1966. 199 p.

5. Dineen, G. W., J. S. Ball, and H. M. Thorne. Composition of Crude Shale Oils. Industrial and Engineering Chemistry. 44(11):2632, 1952.

6. Report on Economics of Environmental Protection for a Federal Oil Shale Leasing Program. Colorado Department of Natural Resources, Draft 1971. 57 p.

7. Environmental and Economic Report on Wyoming Oil Shale. Wyoming Department of Economic Planning and Development, Draft 1971. 57 p.

8. Environmental Problems of Oil Shale. Utah Department of Natural Resources, Draft 1971. 54 p.

9. Environmental Impact Statement for the Prototype Oil Shale Leasing Program. U.S. Department of the Interior, planned for publication in 1974.

10. Personal communication with the U.S. Bureau of Mines, Laramie, Wyoming.

11. Water Pollution Potential of Oil Shale Retorting Residues from Rainfall. Colorado State University. EPA Grant No. 14030 EDB 12/71. U.S. Government Ptg. Office, Washington, D.C.

12. Ward, J. C., G. A. Margheim, and G. O. G. Löf. Water Pollution Potential of Spent Oil Shale Residues from Above-Ground Retorting. (Presented at 161st ACS National Meeting, Los Angeles. March 29, 1971.)

13. Water Pollution Potential of Snowfall on Spent Shale Residues. Colorado State University. U.S. Bur. Mines Grant No. GO111280, directed by The Laramie Energy Research Center, Laramie, Wyoming. Final report in print (June 1972).

14. Kealy, C. D., and R. L. Soderberg. Design of Dams for Mill Tailings. U.S. Bur. Mines, Report No. IC8410, 1969. 49 p.

15. Denson, K. H., et al. Permeability of Sand with Dispersed Clay Particles. Water Resources Research. 4(6): 1275, December 1968.

16. Personal communications with Colony Development Corporation and the Union Oil Company.

17. Carpenter, H. C., H. W. Sohns, and G. W. Dineen. Oil Shale Research Related to Proposed Nuclear Projects. (Presented at the Plowshare Symposium on Engineering with Nuclear Explosives, Las Vegas. January 14-16, 1970.)

18. Hubbard, A. B. Method of Reclaiming Waste Water from Oil-Shale Processing. (Presented at 161st ACS National Meeting, Los Angeles. March 19, 1971.)

19. Montgomery, D. P. Refining of Pyrolytic Shale Oil. I and E C Product Research and Development. 7(4): 274, 1968.

20. Policy on Disposal of Wastes by Subsurface Injection. Federal Water Quality Administration. Communication 5040.10, October 15, 1970.

21. Hite, R. J., and J. R. Dyni. Potential Resources of Dawsonite and Nahcolite in the Piceance Creek Basin, Northwest Colorado. Quarterly of the Colorado School of Mines. 62(3): 591, July 1967.

22. Burwell, E. L., H. C. Carpenter, and H. W. Sohns. Experimental In Situ Retorting of Oil Shale at Rock Springs, Wyoming. U.S. Bur. Mines, Technical Progress Report 16, June 1969. 8 p.

23. Coffin, D. L., et al. Geohydrology of Piceance Creek, NW, Colorado. U.S. Geological Survey Atlas HA-370, 1971.

24. Carver, H. E. Conversion of Oil Shale to Refined Products. Quarterly of the Colorado School of Mines. 59(3): 19, July 1964.

25. Nevens, T. D. Plant and Process for Production of Low Temperature Pumpable Oil from Oil Shale and the Like. U.S. Patent 3,018,243. January 23, 1962.

26. Culbertson, W. J., Jr., et al. Plant and Process for the Production of Oil. U.S. Patent 3,020,209. February 6, 1962.

27. TOSCO Details Costs for Oil Shale Process. Chemical and Engineering News. May 26, 1969. 34 p.

SECTION VIII

APPENDIXES

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APPENDIX A

NATIONAL ENVIRONMENTAL POLICY ACT, 1969

Section 102(2)(C) of Public Law 91-190, National Environmental Policy Act of 1969.

> "The Congress authorizes and directs that, to the fullest extent possible all agencies of the Federal Government shall include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on--
>
> "(i) the environmental impact of the proposed action,
>
> "(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
>
> "(iii) alternatives to the proposed action,
>
> "(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
>
> "(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.
>
> "Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by Section 552 of Title 5, United States Code, and shall accompany the proposal through the existing agency review processes."

APPENDIX B

RETORTING PROCESS DESCRIPTIONS

BUREAU OF MINES GAS-COMBUSTION RETORTING PROCESS[4]

The retort in the gas-combustion process is a vertical, refractory-lined shaft equipped with shale- and gas-handling devices (Figure 3). Crushed shale moves continuously downward through the retort vessel and is preheated by rising, hot retorting products (gases). Next it contacts rising, hot flue gas, is retorted, and is left with a carbonaceous residue. The shale continues downward and the sustained heat of the process removes the carbon residue, leaving burned shale. Burned shale transfers its heat to a rising stream of recycle gas. The cooled, burned shale is mechanically discharged from the bottom of the retort at a rate which controls the overall solids flow through the process. Sustained heat is supplied to the process by introducing a mixture of air and retort gas near the center of the retort. The rising gases and oil vapors are cooled by incoming shale and are collected from the top of the retort.

The gas-combustion process has been pilot-tested at three rates of throughput: 6-, 25-, and 150-tons per day.

UNION OIL COMPANY RETORTING PROCESS[24]

The underfeed retort developed by Union is depicted in Figure 4. A "rock pump" moves shale continuously in a vertical direction through the retort. Ascending shale is preheated by a countercurrent stream of hot flue gas forced downward by blowers. Continuing upward, hot shale is retorted in a burning zone. Oil, noncondensable gases, and cool flue gas are withdrawn from the bottom of the retort. Residual carbon on the spent shale near the top is burned, generating hot flue gas and shale ash. The ash spills into a disposal chute at the top.

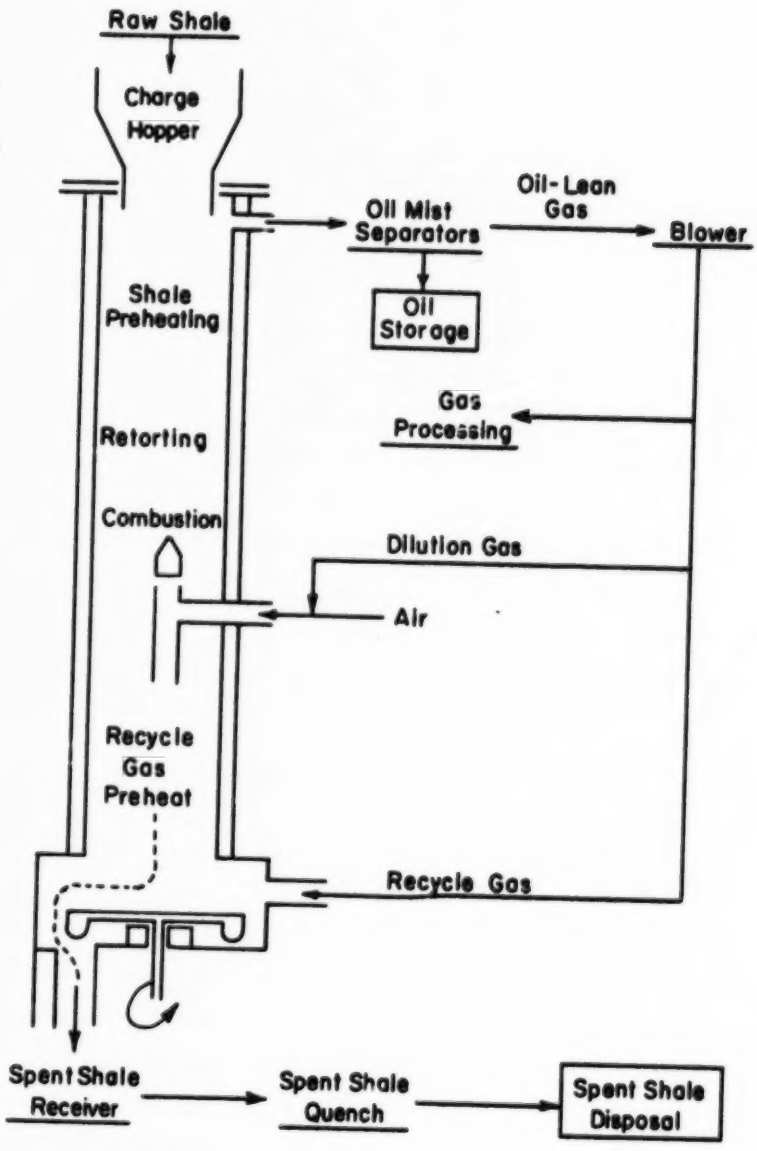

FIGURE 3 - BUREAU OF MINES GAS-COMBUSTION RETORTING PROCESS [4]

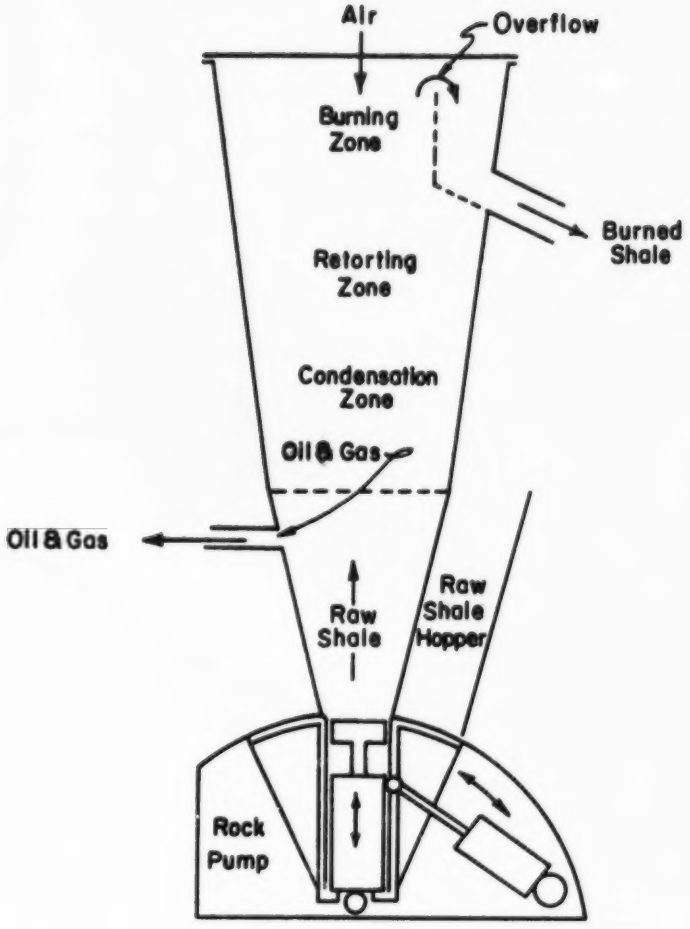

FIGURE 4 - UNION OIL RETORTING PROCESS[24]

TOSCO RETORTING PROCESS[25, 26, 27]

In the TOSCO retorting system, finely crushed, preheated shale and hot ceramic balls are fed to a rotating pyrolysis drum. Direct contact between the two heats the shale to retorting temperatures. Oil vapors and gas are produced and are condensed in two stages to yield heavy oil, crude shale oil, and noncondensable gases. A portion of heavy oil is recirculated to the pyrolysis drum for thermal cracking. The remainder is precooled, then atomized in the first condenser to remove dust aerosol and assist in the condensation. Spent shale and warm balls leave the pyrolysis drum and are screen separated. The warm balls serve to preheat raw shale and are reheated to retorting temperatures by burning noncondensable gases. Spent shale is quenched with water prior to disposal. The original patents describe burning the carbonaceous residue of spent shale in order to provide energy for heating the ceramic balls.[25, 26] The present indication is that this method will not be practiced; however, it is included as an alternate pathway in the process description, Figure 5.

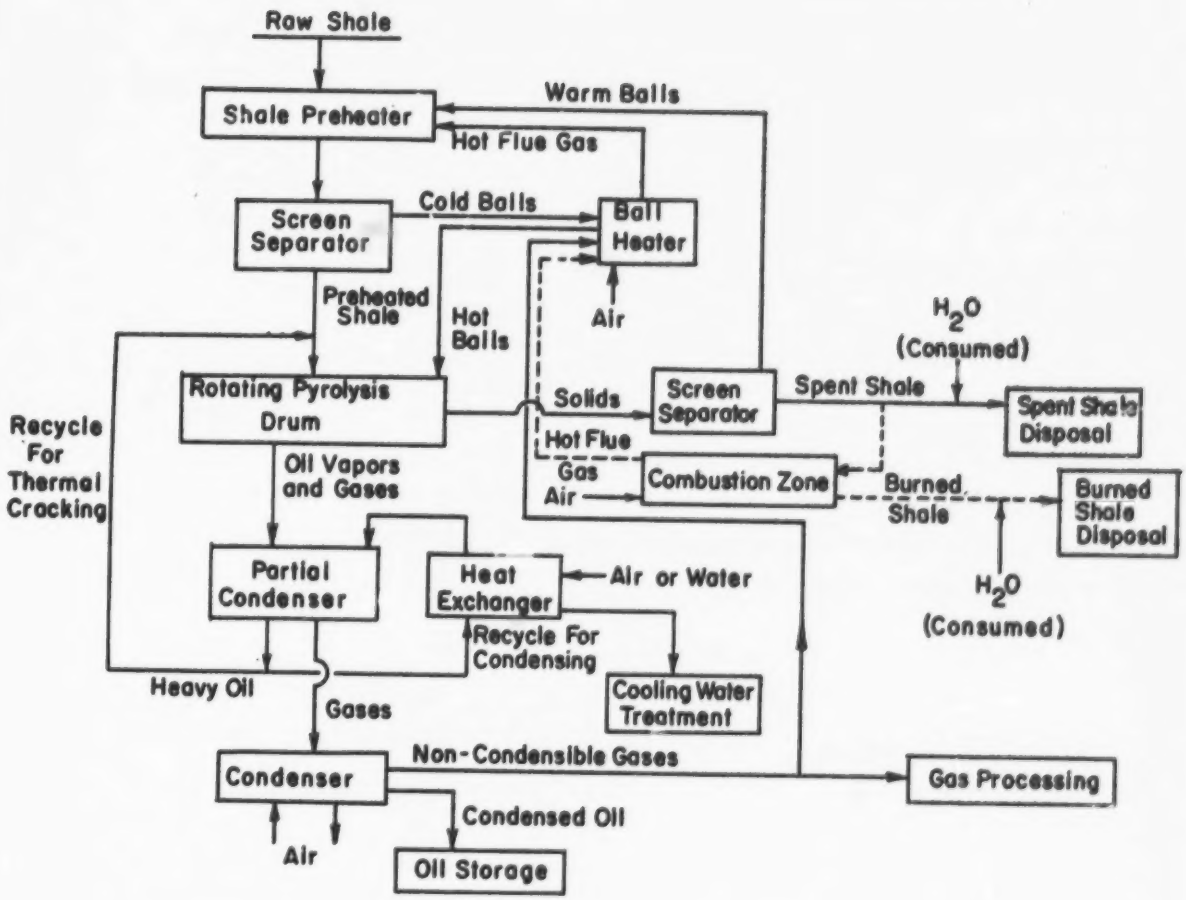

FIGURE 5 - TOSCO RETORTING PROCESS[25, 26, 27]
(Alternate Pathway Dashed)

APPENDIX C

CHARACTERISTICS OF SPENT SHALE--BENCH STUDY[11]

1. Physical Properties

	Bureau Mines	TOSCO	Union
Geometric mean size, cm	0.205	0.0070	(clinkered)
Bulk density, g/ml	1.44	1.30	1.80
Solids density, g/ml	2.46	2.49	2.71
Porosity	0.41	0.47	0.33
Permeability, cm^2	3.46×10^{-9}	2.5×10^{-10}	----
Maximum particle size, cm	<3.81	<0.48	90.
Minimum particle size, cm	>0.0008	>0.0008	30.

2. Leaching Properties: Characteristics of a filtered solution obtained by diluting to one liter a 250 ml aliquot of distilled water blended with a 100 g sample of spent shale.

Sample	pH	Conductivity (μ mhos/cm)	TDS 103° C (mg/l)	Concentrations (mg/l) K+	Na+	Ca++	Mg++	HCO_3^-	Cl^-	$SO_4^=$
Bureau Mines	7.8	1,495	1,090	72	225	42	4	38	13	600
Union	9.9	11,050	10,010	625	2,100	327	91	28	33	6,230
TOSCO	8.4	1,750	1,260	32	165	114	27	20	8	730

3. Leaching Properties: Characteristics of a filtered solution obtained by mechanically shaking one liter of distilled water with a 100 g sample of spent shale for 5 minutes.

Sample	pH	Conductivity (μ mhos/cm)	TDS 103° C (mg/l)	Concentrations (mg/l) K+	Na+	Ca++	Mg++	HCO_3^-	Cl^-	$SO_4^=$
Bureau Mines	7.8	1,320	970	--	--	--	--	--	--	--
TOSCO	8.4	1,640	1,121	10	206	102	31	20	6	775

4. Leaching Properties: Characteristics of leachate collected as a result of percolating a two cm constant head of distilled water through a ten cm diameter column containing 12.5 kilograms of TOSCO spent shale.

Volume of Leachate Sample (ml)	Cumulative Volume of Leachate (ml)	Cond. (μ mhos/cm)	Concentrations (mg/l) Na+	Ca++	Mg++	$SO_4^=$	Cl^-
254	254	78,100	35,200	3,150	4,720	90,000	3,080
340	594	61,600	26,700	2,140	3,720	70,000	1,900
316	910	43,800	14,900	1,560	2,650	42,500	910
150	1,060	25,100	6,900	900	1,450	21,500	370
260	1,320	13,550	2,530	560	500	8,200	200
125	1,445	9,200	1,210	570	580	5,900	140
155	1,600	7,350	740	580	470	4,520	140
250	1,850	6,820	500	610	540	4,450	80
650	2,500	5,700	---	---	---	---	---
650	3,150	4,800	---	---	---	---	---
650	3,800	4,250	---	---	---	---	---
760	4,560	3,850	---	---	---	---	---

APPENDIX D

TOSCO SHALE CHARACTERISTICS AND EMPLACEMENT--PILOT STUDY

Description of TOSCO II Spent Shale Sample

Maximum Particle Size--<0.476 cm
Minimum Particle Size-->0.00077 cm
Geometric Mean Size--0.0070 cm
Geometric Standard Deviation--3.27
Solids Density--2.49 g/cc
Bulk Density--1.30 g/cc

Description of Spent Shale Emplacement

Approximately 68 tons of unweathered retorted shale were placed in a pile measuring 80 feet long, 8 feet wide at the maximum depth of 2 feet, and 12 feet wide at the surface. The shale was placed at a slope of 0.75%. The reader is referred to Ward, et al. for details of the facility and the rainfall results.[12]

Initially, the shale had a surface density (top 3 in.) of 86 lb/ft^{-3}. Later in the rainfall study the shale was compacted, whereupon the figure became 101 lb/ft^{-3}. The average density below the surface remained unchanged at 55 lb/ft^{-3}. The surface density was reduced to 75 lb/ft^{-3} following snowmelt and shale saturation.